3.2 RENEWABLE ENERGY APPLICATIONS FROM NASA SATELLITE ANALYSIS AND MODELING

Charles H. Whitlock*[1], Paul W. Stackhouse, Jr. [2], William S. Chandler[1], James M. Hoell[1], Taiping Zhang[3]

[1]Science Applications International Corporation, Hampton, VA
[2]NASA Langley Research Center, Hampton, VA
[3]Analytical Services and Materials, Inc., Hampton, VA

1. INTRODUCTION

NASA's Earth Science Enterprise (ESE) has long supported satellite systems and research providing data important to the study of climate and climate processes. These data include long-term estimates of meteorological quantities and surface solar energy fluxes. Satellite based products have been shown to be accurate enough to provide reliable solar resource data over regions where surface measurements are sparse or nonexistent (Whitlock et al. 2001; Perez et al. 2002). NASA supported the development of the Surface meteorology and Solar Energy (SSE) dataset providing Internet-based access to parameters formulated specifically for photovoltaic and renewable energy system design needs. Now, NASA has established an Energy Management theme within the ESE Applications Program. Under this program, the Prediction Of Worldwide Energy Resource (POWER) project (Stackhouse et al. 2004) has been initiated both to improve subsequent releases of SSE and to create new datasets directly applicable to other industries from new satellite observations and the accompanying results from forecast modeling.

This paper gives an overview of the NASA POWER activities related to the development of parameters for the renewable energy industry. Plans for upgrades to the SSE dataset are reviewed, and the vision of POWER towards the development of decadal datasets through the use of data emerging from NASA's most recent satellite missions and meteorological reanalysis data.

2. CURRENT SSE DATA

The original SSE data-delivery web site, intended to provide easy access to parameters needed in the renewable energy industry, was released to the public in 1997. The solar and meteorological data contained in this first release was based on the 1993 NASA/World Climate Research Program Version 1.1 Surface Radiation Budget (SRB) science data and TOVS data from the International Satellite Cloud Climatology Project (ISCCP). The parameters provided in this first version were formulated to be non-industry specific.

This initial design approach proved to be of limited value because of the use of "traditional" scientific terminology that was not compatible with terminology/parameters used in the power industry to design renewable energy power systems. After additional consultation with industry partners, Release 2 SSE was made public in 1999. That version (and subsequent Releases 3 and 4) followed a marketing and product update philosophy after Zyman (1999). The procedure actually used is described in DiPasquale et al. (2002). The process may be briefly summarized as "Ask your potential customers what they need at several stages of development and give it to them." Details of the releases 3 and 4 web sites and their use are given in Chandler et al. (2003 and 2004). Approximately 25,800 individual users have downloaded nearly 502,300 data files from the SSE web site between June 1999 and July 2004. Registered users are presently downloading approximately 10,000 data documents each month at no cost. Over 200 different parameters are available on a monthly-average basis for each 1^{o} cell on Earth. A data document may contain either digital values or be a map of digital values as defined by the web site user. NASA has partnered with a number of industry organizations as well as several government agencies in order to provide industry-focused data available from a user-friendly web-based data archive. Organizations involved are given in the Partners and Performance section accessible from the Release 4 SSE Home Page (<http://eosweb.larc.nasa.gov/sse>).

Accuracy of both the radiation and meteorology values derived from satellite and reanalysis data has constantly been under review. The accuracy and methodology used to develop each release is described in the documentation available through the SSE web site. Estimated monthly accuracies for Release 4 SSE relative to ground site data are given in Figure 1. Values are based on various combinations of ground site data provided by the DOE National Renewable Energy Laboratory, Natural Resources Canada, the NOAA Climate Monitoring and Dynamics Laboratory, the Swiss Federal Institute of Technology, the World Radiation Data Center, the University of Texas, and the State University of New York at Albany's Atmospheric Research Center. From 200 to more than 1000 ground-site values were usually available, depending on the parameter. Absolute accuracies of the ground site data are unknown.

* *Corresponding author address:* Charles H. Whitlock, Science Applications International Corporation, One Enterprise Parkway, Suite 300, Hampton, VA 23666-5845; e-mail: c.h.whitlock@larc.nasa.gov

MONTHLY SSE RELEASE 4/GEOS-1 ESTIMATED UNCERTAINTY

Parameter	Method	RMS (Bias)
Horizontal Insolation	SSE satellite-based Staylor	10 to 17% (± 3%)
Horizontal Diffuse Radiation	SSE/Erbs et al. correlation	~ 18% (+ 4%)
	SSE/Extended Page (74 reference sites)	~ 20% (+ 3%)
Direct Normal Radiation	SSE/RETScreen-type (hourly angular conversion)	~ 15% (- 9%)
	SSE/Extended Page (empirical Staylor angular conversion)	~ 24% (+ 2%)
Flat, Rough Grass Wind (10-m height)	Documented 10-m height airport sites	1.3 m/s (-0.2 m/s)
	Unknown-height airport sites	1.3 m/s (0.0 m/s)
Air Temperature, K (10-m height)	Global sites ≤ 243K	3.2% (NA)
	Global sites ≥ 263K	1.1% (NA)
	Global sites between 243K and 263K	Linear variation
	200 potential renewable energy sites in 7 continental regions	1.2% (NA)
Heating Design Temperature, K	200 potential renewable energy sites	1.3% (NA)
Cooling Design Temperature, K	200 potential renewable energy sites	1.4% (NA)
Summer Mean Daily Temperature Range, K	200 potential renewable energy sites	0.9% (NA)
Heating Degree-Days Below 18-deg C, deg-days	200 potential renewable energy sites	15% (NA)
Relative Humidity, %	Global	18.5% of mean
	200 potential renewable energy sites	10% of mean
Surface Pressure, kPa	Global	3.8% (NA)
	200 potential renewable energy sites	2.4% (NA)

Fig. 1. Estimated Uncertainty for Release 4 SSE data.

3. THE POWER PROJECT

As noted above, the POWER Project seeks to use new, more accurate science data to both upgrade the Release 4 SSE and assist other industries in meeting national needs. The POWER plan is briefly summarized in Figure 2. A key goal is to improve both time and spatial resolution of the Release 4 SSE data as well as to add additional parameters in subsequent SSE releases. Release 5, for example, will provide a significant improvement in spatial resolution. The spatial resolution of the data provided in Releases 3 and 4 is on a 1^{o} cell format interpolated from a $2+^{o}$ grid format* used in the original radiation and meteorology science data that were inputs to SSE processing.

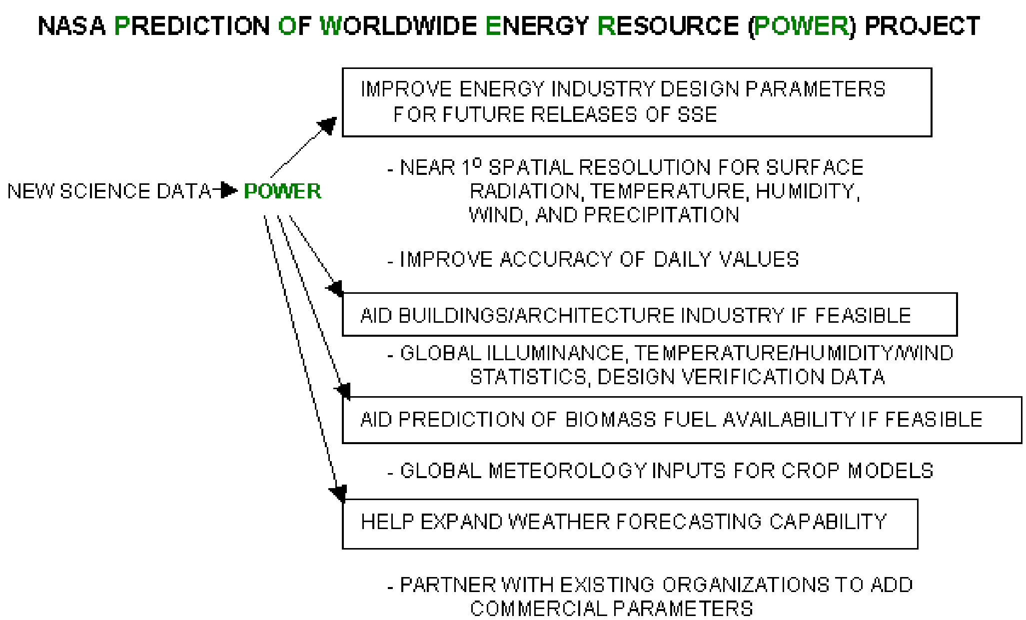

Fig. 2. Goals of the POWER Project.

The spatial resolution of Release 5 will be based on radiation and meteorology science data in near 1^{o} formats** which are now becoming available (Release 2 SRB and GEOS-4). Higher spatial resolution and accuracy in the science data allows more rational estimates of daily values for 1^{o} cells as well as more accurate values for some monthly-average parameters. Figure 3 indicates that hourly clouds based on near 1^{o} science data are more consistent with topographic features than the Release 4 hourly clouds, even when averaged over 10 years.

Figure 4 shows an effect of the improved Release 5 cloud fractions at the town of Hermiston in northeastern Oregon. The 10-yr average mid-day radiation for July (Fig. 3) suggests that Release 4 SSE has a lower cloud fraction, and probably more solar radiation, than Release 5 SSE in that region. Figure 4 indicates that Release 4 SSE is in fact estimating too much radiation from mid-summer through September. Release 5 values are much closer to ground site values. Similar improvements of Release 5 over Release 4 daily radiation values have been observed for a number of other agricultural sites in the world. Agroclimatology parameters required by agricultural Decision Support Systems are currently under study based on the success of the SSE web based activity. Daily averaged solar radiation, precipitation, and air temperatures are items to be studied.

RELEASE 4 INTERPOLATED 1-DEG VALUES **FUTURE RELEASE 5 SSE 1+ DEG VALUES**

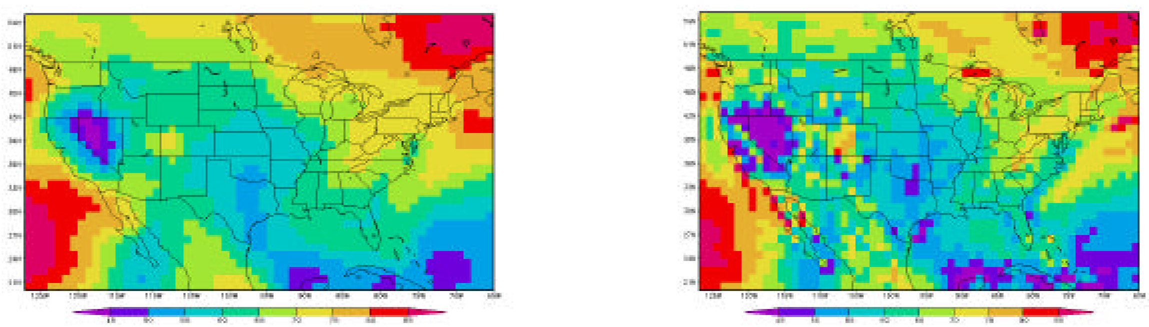

Fig. 3. Effects of Spatial Resolution on 1983-1993 Average Cloud Fraction in July at 1800 GMT (%).

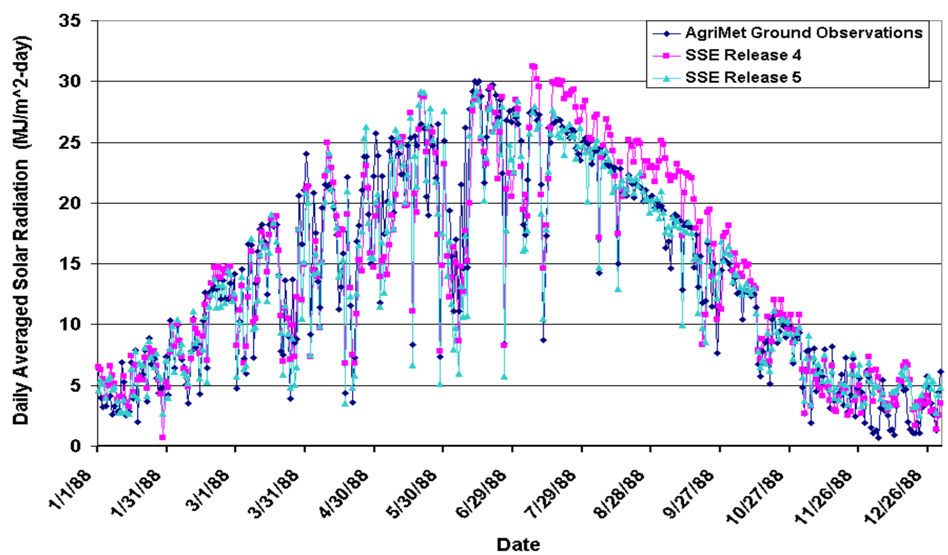

Fig. 4. Time series of the daily averaged solar radiation from AgriMet Ground Observations (<http://www.usbr.gov/pn/agrimet/index.html>) at Hermiston, Oregon (45.6^{o} N, 119.28^{o} W) and Release 4 and 5 SSE data for 1988. Notice that the Release 4 data tends to over estimate the solar radiation during the July through September period, while Release 5 data more closely agrees with the ground observations. Over estimations by the release 4 data during the July through September period was typical for the time period of the Release 4 data.

Residential and commercial buildings consume 36% of the total energy and 65% of the electricity in the United States (Wilson and Yost 2001). We now have the capability to design buildings that use 50% less energy at no increase in cost if accurate environmental data are known. New parameters and statistics can also help the buildings/architecture industry improve efficiency in many regions. Whitlock et al. (2002), describe needs of the buildings/architecture industry. Figure 5 is a listing of parameters used to design energy-efficient buildings around the world. The items listed in red are parameters not provided in Release 4 SSE. Most items are not available except in cities with large airports. The buildings community desires at least 70 additional parameters beyond SSE.

As noted in Figure 2, new parameters could also be added to existing weather forecasting models now operated by a number of government and commercial organizations. Figure 6 illustrates some energy-related activities that upgraded forecast capability could provide. POWER is moving ahead with plans to evaluate the prediction of parameters as discussed above from atmospheric models by continued partnerships with entities like the National Renewable Energy Laboratory (NREL) and developing partners with NOAA and other researchers.

NASA DATA FOR 64,800 1-DEGREE CELLS OVER GLOBE

Available "OLD DATA" at Release 4 SSE web site
Planned in ~ 2 yrs in Buildings/Architecture data set

10-m HEIGHT AIR TEMPERATURES:

MONTHLY - Mid-latitude/high-latitude/artic heating and mid-latitude cooling dry-bulb degree days; mean, max, min, amplitude, standard deviation, ASHRAE 0.4%, 1%, & 2% dry-bulb; mean, max, min, amplitude, standard deviation, 0.4%, 1%, & 2% wet-bulb, mean humidity ratio.

ANNUAL - ASHRAE heating 99.6% & 99% dry-bulb; coldest-month 0.4% & 1% mean dry-bulb; max & min extreme annual daily mean and standard deviation dry-bulb; Cooling warmest-month 0.4%, 1%, 2%, and mean dry-bulb, wet-bulb, dew-point temperatures and humidity ratio; mean daily dry-bulb range for the warmest month; return period for extreme annual temperatures.

EARTH SKIN TEMPERATURE: MONTHLY

WIND:

MONTHLY - 10-m speed (17 different vegetation/surface types), 50-m, 100-m, 150-m, & 300-m speeds. 50-m speed frequency (speed range vs % of time), prevailing 50-m wind direction vs wind speed.

ANNUAL - ASHRAE airport-type surface 10-m extreme annual 1%, 2.5%, and 5% speed, coldest-month speed at 0.4% and 1% frequency of occurrence conditions, mean speed and prevailing wind direction coincident with the above 99.6% and 0.4% dry-bulb temperatures.

RADIATION:

MONTHLY - Both all-sky and clear-sky total & diffuse radiation and illuminance on ASHRAE north (n), northeast (ne), east (e), southeast (se), south (s), southwest (sw), west (w), & northwest (nw) facing surfaces at 0, 30, 45, 60, and 90 deg tilt angles, mostly-clear % of daylight hours, photosynthetically-available radiation.

PRECIPITATION: MONTHLY - mean, max, and min.

AVG WITHIN-MONTH, 3-HOURLY VARIATION - Sun elevation & azimuth, radiation & illuminance on ASHRAE n, ne, e, se, s, sw, w, & nw facing surfaces at 0, 30, 45, 60, and 90 deg tilt angles, temperatures, humidity ratio, wind speeds & direction.

SELECTED 1-YEAR HOURLY DATA IN TMY FILE FORMAT: (Need more study on this!)

Fig. 5. Parameters Needed by the Buildings/Architecture Industry.

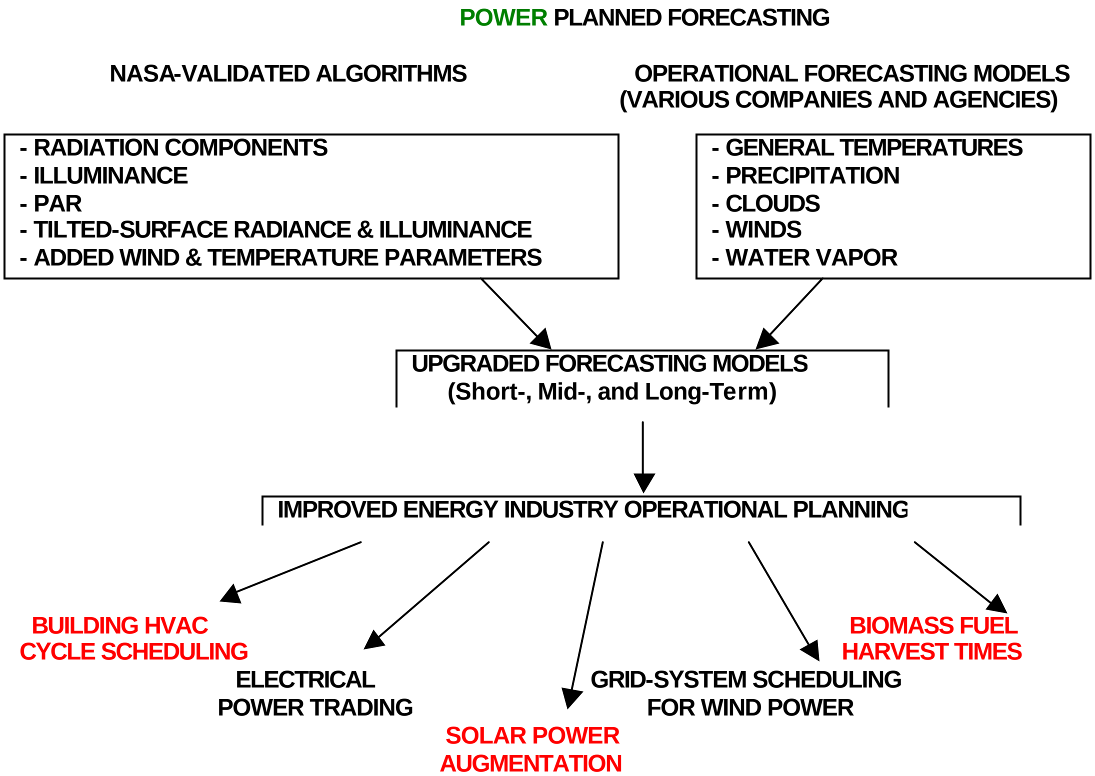

Fig. 6. POWER Goals To Help Expand Weather Forecasting Capability.

4. CONCLUSIONS

The Power project is striving to provide from NASA satellite analysis and modeling global data sets specifically designed to meet the needs of engineers and architects designing renewable energy systems. These systems are maturing to the point that utility companies are planning to incorporate energy production by these systems into distribution of electricity of electric energy to power grids. The POWER project is contributing to the optimal use of these technologies by providing environmental data essential to the optimization of these systems. The release of the Surface meteorology and Solar Energy data set/version 5 will represent the next step in these improved data sets. This new data is scheduled for release this fall. In addition, data sets and web site access to pilot data sets specifically designed for buildings and agricultural applications will be made available next year. Finally, POWER will be continuing old partnerships and initiating new ones towards the prediction of parameters from atmospheric models.

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* The original Release 4 SSE radiation data were in a 280 x 280 km grid system over the globe. The GEOS-1 meteorology data were in a 2.5^o longitude x 2^o latitude grid system over the globe. These values were interpolated to the SSE 1^o x1^o grid system using a bi-linear interpolation algorithm.

** The original radiation data for future releases of SSE is in a true 1^o x 1^o grid for latitudes from 0 to $\pm$ 45^o, 2^o longitude x 1^o latitude for latitudes between $\pm$45^o and $\pm$70^o, 4^o x 1^o for latitudes between $\pm$70^o and $\pm$80^o, 8^o x 1^o for latitudes between $\pm$80^o and $\pm$89^o, 120^o x 1^o for latitudes between $\pm$89^o and $\pm$90^o. The variable cell width dimensions (in degrees) are required at high latitudes in order to obtain enough cell area for accurate cloud fraction values from satellite data. Radiation values are transformed to a true 1^o format using a replication algorithm in the longitudinal direction for latitudes above 45^o or below -45^o. The GEOS-4 meteorology data are in a 1.25^o longitude x 1^o latitude grid system over the globe. These values are interpolated to the SSE 1^o x1^o grid system using a bi-linear interpolation algorithm.